FTD-MT-24-2121-71

FOREIGN TECHNOLOGY DIVISION

A PROGRAM FOR THE EQUIVALENT TESTING
OF GAS-TURBINE ENGINES

by

N. D. Kuznetsov and V. I. Tseytlin

18

Approved for public release;
distribution unlimited.

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Foreign Technology Division Air Force Systems Command U. S. Air Force	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

A PROGRAM FOR THF EQUIVALENT TESTING OF GAS-TURBINE ENGINES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Translation

5. AUTHOR(S) (First name, middle initial, last name)

Kuznetsov, N. D. and Tseytlin, V. I.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1970	13	

8a. CONTRACT OR GRANT NO. b. PROJECT NO. G101 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) FTD-MT-24-2121-71 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Foreign Technology Division Wright-Patterson AFB, Ohio

13. ABSTRACT

Verifying the reliability of engines for prolonged service life by conducting protracted tests for a given service life does not assure rapid rates of growth of service life necessary to increase the profitability of air transportation. To accelerate the rate of growth of service life and check on the capabilities of engines for prolonged service life it is necessary to conduct accelerated tests according to a program which will assure equivalence of the loading of units and parts for a given service life. In this paper we give the basis for a program of accelerated equivalent tests of engines, compiled from analysis of the factors that exhaust the service life of units and parts. It can be recommended as a standard program. The operating features of specific engines should be taken into consideration by appropriate changes and supplements to the proposed program.

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Gas Turbine Engine						
Reliability						
Stress						
Creep						
Blade						
Shaft						

UNCLASSIFIED

Security Classification

FTD-MT-24-2121-71

EDITED MACHINE TRANSLATION

A PROGRAM FOR THE EQUIVALENT TESTING
OF GAS-TURBINE ENGINES

By: N. D. Kuznetsov and V.I. Tseytlin

English pages: 13

Source: Problemy Prochnosti (Problems of Strength).
No. 10, 1970, pp. 14-19

This document is a SYSTRAN machine aided translation, post-edited for technical accuracy by: John Miller.

UR/3663-70-000-010

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

A PROGRAM FOR THE EQUIVALENT TESTING OF GAS-TURBINE ENGINES

N. D. Kuznetsov and V. I. Tseytlin
(Kuybyshev)

Verifying the reliability of engines for prolonged service life (5000-10,000 hours) by conducting protracted tests for a given service life does not assure rapid rates of growth of service life necessary to increase the profitability of air transportation.

To accelerate the rate of growth of service life and check on the capabilities of engines for prolonged service life it is necessary to conduct accelerated tests according to a program which will assure equivalence of the loading of units and parts for a given service life.

In this paper we give the basis for a program of accelerated equivalent tests of engines, compiled from analysis of the factors that exhaust the service life of units and parts. It can be recommended as a standard program. The operating features of specific engines should be taken into consideration by appropriate changes and supplements to the proposed program.

Factors which determine the service life. Stress-rupture strength, creep, and relaxation of stresses limit the longevity of "hot" engine parts, mainly of the turbine: the vanes, disks, guide vanes, bolt connections, and others.

The influence of these factors depends on stress, temperature, their combination in time, and the frequency of the loading. Satisfactory coincidence of the results of experiments with combination loading under various conditions, and calculations which take into consideration the exhausting of the service life by individual regimes, is obtained when evaluating the equivalent longevity by the formula

$$\tau_{экв} = \frac{1}{\sum_{i=1}^{z} \frac{c_i}{\tau_i}},$$

where z is the number of loading regimes; c_i is the percentage of accrued operating time in an individual regime, calculated from the condition $\sum_{i=1}^{z} c_i = 1$; τ_i is the longevity to destruction with stress σ_i and temperature t_i, obtained from curves of the stress-rupture strength, with consideration of the influence of loading frequency.

Knowing the conditions for operation of a part in each specific regime, and having the actual time distribution of regimes with respect to the service life, we can find the required time of operation in an equivalent regime which will assure the same reserve strength factor as in the operating regime.

Endurance determines the longevity of the majority of engine parts – blades, shafts, housings, casings, supports, bolt connections, pipelines, unit suspensions, etc.

Resistance to variable loads, based on the test conditions, depends on the stress level, the asymmetry of the cycle, and the loading combination.

For a comparative estimate of the equivalence of regimes relative to variable stresses, in first approximation we can use a formula for damage summation, analogous to the formula for equivalent longevity when estimating stress-rupture strength:

$$N_{экв} = \frac{1}{\sum_{i=1}^{z} \frac{c_{N_i}}{N_i}},$$

where c_{N_i} is the percentage of accrued operating time with frequency reduced to the form of oscillations with maximum stresses; N_i is the maximum longevity (in cycles) from the curve of endurance at a given level of variable stresses σ_v with consideration of the reserve factors used and the true asymmetry.

The influence of asymmetry in this case can be approximately taken into consideration by means of the formula $\sigma_p = \sigma_{-1}\left(1 - \frac{\sigma_m}{\sigma^t_{в/\tau}}\right)$, obtained under the assumption of a linear change in endurance with increasing asymmetry (σ_p is the endurance limit for an asymmetric cycle; σ_{-1} is the endurance limit for a symmetrical cycle; σ_m is the average stress of the cycle; $\sigma^t_{в/\tau}$ is the stress-rupture strength with respect to service life τ at temperature t).

If we assume that between σ and N there is a linear dependence in logarithmic coordinates, then

$$N = \frac{A}{\sigma^a}.$$

Setting

$$K_p = \frac{1}{1 - \frac{\sigma_m}{\sigma^t_{в/\tau}}},$$

we can write

$$N_{экв} = \frac{A}{K_v^a} \cdot \frac{1}{\sum_{i=1}^{z} c_{N_i} (K_p K_j \sigma_{v_i})^a},$$

where K_v is the reserve factor relative to variable stresses, for which the equivalent longevity is determined; A and a are constants, defined for each material; K_f is a factor which takes into account the distribution of stresses for a given form of oscillations.

To determine the equivalent longevity we must have the results strain-gauge measurements for the various forms of oscillations, and the allocation of stresses and the accrued operating times, by regimes.

The frequency of static loading, determined by the arrivals at maximum revolutions and loads, with a long service life has a substantial influence on strength.

Most sensitive to loading frequency are stressed parts made of high-strength steels and titanium alloys, particularly those that are notched (rotor joints, disks with apertures, shafts), and also welded and cast units (combustion-chamber housings, compressor stator, supports). The influence of loading frequency on strength with increasing numbers of cycles is shown in Table 1.

The loading frequency also influences the stress-rupture strength. Table 2 shows, for certain materials, the coefficient of sensitivity to repeated loads K_N, defined as the ratio of stress-rupture strength during repeated loading to its value with continuous testing.

Table 1

Type of sample	Material	$K_N = \frac{\sigma_N}{\sigma_B}$		
		200 cycles	1000 cycles	5000 cycles
Smooth	ВМЛ-3	0,8	0,67	0,54
	ВТ-8	1,0	0,9	0,74
	23Х13НВМФА	1,0	0,85	0,64
Notched $r_в = 0,1$ mm	ВМЛ-3	0,71	0,55	0,4
	ВТ-8	1,0	0,7	0,39
	23Х13НВМФА	0,68	0,5	0,32
	1Х12Н2ВМФ	0,9	0,72	0,54
Welded	Х1[illegible]Н20Т3Р	1,0	0,86	0,68

Table 2

Material	Test temperature, °C	$K_{N/\tau} = \frac{\sigma_{N/\tau}}{\sigma_{B/\tau}}$	
		100 cycles	1000 cycles
4Х12Н8Г8МФБ	600	0,94	0,91
	700	0,78	0,67
4Х15Н7Г7Ф2МС	800	0,9	0,85
ХН77ТЮР	550	0,93	0,92
	750	0,75	0,67
ЖС-6К	800	0,92	0,89
	1000	0,75	0,67

Equivalence of tests on loading frequency consists in maintaining, during accelerated testing, the same number of arrivals at maximum loads as during ordinary tests.

Heat resistance limits the longevity of turbine rotor and guide vanes, combustion chambers, rear supports, and other parts subjected to rapid heating and cooling during startups, response tests, and decelerations.

A condition for the absence of cracks during repeated heatings with a one-way temperature differential is the following:

$$\sigma_{\text{упр}} < 2\sigma_{0,2}.$$

Under conditions of elastic stresses, due to a difference in temperatures which are less than twice the yield point $\sigma_{0.2}$ there is adaptability of the material, and there will be no cracks even with practically unlimited heat exchanges. The condition for adaptability with alternating heating can be as follows:

$$\sigma_{\text{упр}} < \sigma_{0,2}.$$

Under the combined influence of a temperature differential and force factors σ_p (gas forces, inertia, and others), the maximum permissible conditional stresses to assure adaptability are defined by specific calculations.

In an equivalent program, the number of heat exchanges and the nature of the temperature rise under nonsteady-state conditions should correspond to analogous conditions in the program for ordinary engine tests.

Wear and contact fatigue of parts can have a significant influence on longevity. Wear of slide-valve couples, labyrinth seals, and other contacting surfaces can lead to disruption of the control system, a change in the unloading of active forces and superchargings, disruption of normal operation of splines, gears, and bearings.

It is possible to estimate the equivalent longevity of gears and bearings relative to contact fatigue if we know the makeup of the regimes and their accrued operating time in programs of stress-rupture and equivalent tests; we use the formula

$$L_{\text{экв}} = L_{\text{дл}}\left(\frac{\beta_{\text{дл}}}{\beta_{\text{экв}}}\right)^m,$$

where $L_{\text{дл}}$ and $L_{\text{экв}}$ are the durations of the stress-rupture and equivalent test programs, respectively; $\beta_{\text{дл}}$ and $\beta_{\text{экв}}$ are the coefficients of load reduction in the stress-rupture and equivalent test programs, respectively,

$$\beta = \sqrt{\sum_{i=1}^{z} c_i\left(\frac{n_i}{n_{\text{в}}}\right)\left(\frac{P_i}{P_{\text{в}}}\right)^m},$$

where m = 3.33 for ball and roller bearings; m = 3 for case-hardened gears; $n_{\text{в}}$ and $P_{\text{в}}$ are the revolutions and load under takeoff conditions; n_i and P_i are the revolutions and load under arbitrary conditions.

To establish a correspondence between the equivalent program and the program of stress-rupture tests relative to wear and contact fatigue of certain elements it is advisable, in individual cases, to change the active loads due to a change in pressure in the chambers or for other reasons. For example, for radial thrust bearings, using the dependence of longevity on axial force (Fig. 1), we can assure, for the selected program of accelerated tests, equivalence with the program of stress-rupture tests.

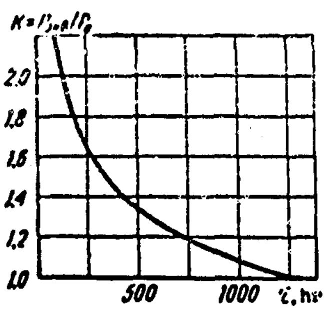

Fig. 1. Accrued operating time of bearing under take-off conditions, equivalent to 5000 hours (K - increase of axial force on bearing).

The program of equivalent tests. To accelerate verification of the influence of the above-indicated factors on the longevity of parts it is necessary to include, in the program of equivalent tests, the accrued operating time under maximum and takeoff conditions, "cold" starts with access to takeoff conditions, accelerations and decelerations with holding under takeoff conditions, accrued operating time at resonance and critical revolutions, startups, and accelerations.

Below we give a program of equivalent tests for one engine; this program, with certain changes to account for the operating features of various engines, can be recommended as a standard program. The program was compiled under the condition that a 5000-hour program of prolonged bench tests is replaced with a 1000-hour equivalent-test program.

Accrued operating time under maximum conditions at maximum gas temperature exhausts the stress-rupture strength of hot engine parts. A calculation of the necessary accrued operating time using, as our example, a moving turbine blade made of ЖС-6К material is given below. The blade operating conditions in various regimes and the corresponding percentages of accrued operating time c_i and the maximum longevities τ_i are given in Table 3.

Table 3

Regime	t_{non}, °C	σ_Σ, kgf/mm²	$K_m\sigma_\Sigma$, kgf/mm²	c_i	τ_i, hr
Maximum	850	12,8	34,0	0,02	200
Rated	800	12,1	32,0	0,21	2300
0.85 of rated	760	11,3	30,0	0,35	20000
0.7 of rated	730	10,4	27,5	0,17	$>10^5$
0.6 of rated	710	9,8	26,0	0,12	$\gg 10^5$
0.4 of rated	650	8,3	22,0	0,09	$\gg 10^5$
Idle	450	4,1	10,9	0,03	$\gg 10^5$

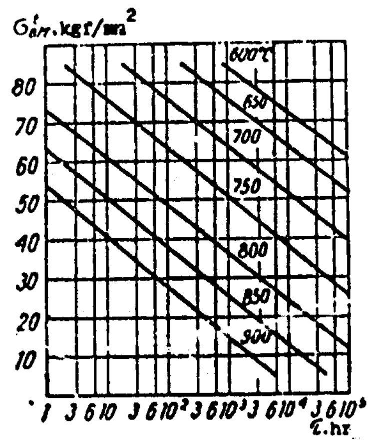

Fig. 2. Stress-rupture strength of alloy ЖС-6К.

The values of τ_i were determined from the curves of stress-rupture strength (Fig. 2) with a reserve factor K_m = 2.65 which corresponds, for the given allocation of regimes relative to service life, to longevity τ = 5000 hours.

If we assume from the equivalent program that c_i = 1, i.e., assume that service life is shortened only under maximum conditions, the accrued operating time necessary under these conditions to exhaust such a longevity, from the program of prolonged tests for 5000 hours, will be $\tau_{экв}$ = 210 hours (Fig. 3).

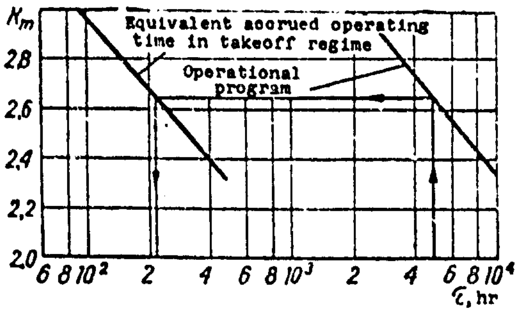

Fig. 3. Equivalent longevity of moving turbine blades.

Table 4

Regime	c_i	$\frac{n_i}{n_B}$	$\frac{P_i}{P_B}$	$\left(\frac{P_i}{P_B}\right)^{3.33}$	$c_i \frac{n_i}{n_B}\left(\frac{P_i}{P_B}\right)^{3.33}$
Takeoff	0,02	1	1	1	0,02
Rated	0,21	0,94	0,84	0,563	0,112
0.85 of rated	0,35	0,89	0,71	0,316	0,098
0.7 of rated	0,17	0,83	0,59	0,171	0,024
0.6 of rated	0,12	0,78	0,51	0,107	0,010
0.4 of rated	0,09	0,66	0,34	0,025	0,001
Idle	0,03	0,33	0,08	0,000	0,000

Under takeoff conditions we checked the strength, fatigue limit, and wear resistance of gears, bearings, and spline connectors. In this regime, maximum powers and inertial and gas loads are transmitted.

The required operating time under takeoff conditions to assure equivalent longevity relative to contact fatigue is given below, using the calculation of bearings as our example.

Table 4 shows the loads and percentages of accrued operating time under various conditions.

The reduction coefficient for the prolonged program $\beta_{экв}$ = 0.67. From the equivalent program, with accrued operating times only under takeoff conditions, $\beta_{экв}$ = 1 and $L_{экв}$ = 1350 hours.

After compiling the program of equivalent tests with consideration of the exhausting of longevity in other regimes (besides the takeoff regime), the indicated longevity can be refined and, if necessary, the axial force on the bearing can be changed by redistributing the system of loads.

Cold starts and entry into the takeoff regime provide a check of the thermal impact of "hot" parts, mainly turbine disks with a maximum temperature differential between the crown and the hub. Figure 4 shows characteristic curves of heating of the crown and hub during cold startup and entrance into the takeoff regime. From the graph we see that the temperature differential during warmup is substantially higher than in a steady-state regime.

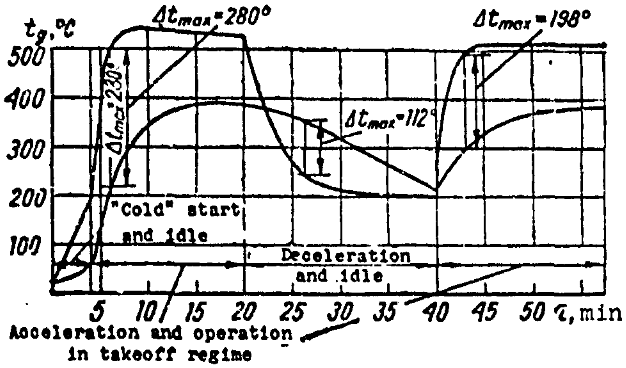

Fig. 4. Temperature of a turbine disk in nonsteady-state regimes.

To verify the reliability of operation of disks under these conditions, during the equivalent tests the number of entries of a "cold" engine to takeoff conditions should correspond to the number based on the total program. When conducting ordinary prolonged tests, only the first startups of the stage are "cold." Consequently, in an equivalent program corresponding to 5000 hours of accrued operating time, there should be 500 "cold" startups, which is equal to the number of stages in the total program if the tests are conducted in 10-hour stages.

If there must be prolonged standing between stages (2-3 hours) with sufficiently complete cooling of the disks, the total duration of the equivalent tests increases somewhat. To shorten this time, in individual cases we should reduce the number of "cold" starts and increase the duration of the stages, particularly for an engine with a rather long continuous-flight range.

Engine acceleration and deceleration with holding in the takeoff mode and idle also provide mainly for verification of the strength of disks with a maximum inverse differential, i.e., under conditions when the temperature of the crown is less than that of the hub and maximum temperature tensile stresses occur on the crown.

After entry into the takeoff mode and the maximum hub temperature has been reached, there should be deceleration, holding at idle until the maximum reverse differential has been reached after several minutes (see Fig. 4), and acceleration to the takeoff mode. In this case there will be maximum tensile stresses (temperature and inertia) on the crown. The total number of such operations in the equivalent program should correspond to the possible number of analogous operations in the program for total accrued operating time.

In these tests we also check the wear resistance and run-in of the labyrinth seals, since the stator parts, cooled more rapidly than the rotor parts, have maximum recovery of the working clearances. Depending on the position of the labyrinth seals, this process can occur during decelerations or accelerations.

When operating in resonance regimes we check the fatigue limit of the shaped part of the rotor and guide vanes with oscillations of various forms (mainly, higher), the disks, and also the contact fatigue of the blade joints.

To estimate the required accrued operating time in the equivalent program, in one of the resonance regimes we must have detailed results of strain-gauge measurements for all forms of oscillations and corresponding stress distribution.

Let us examine, as an example, the moving blade of a compressor. Table 5 gives the measured stresses for various forms of oscillations, the corresponding frequencies, the scaling factors, and the average stresses by regimes. The table also gives the maximum longevities with reserve factor $K_v = 5$.

The equivalent longevity based on the program of long-term tests for a blade made of BT3-1 material, with parameters of the fatigue-limit curve $A = 4 \cdot 10^{31}$ and $a = 16$ and a reserve factor $K_v = 5$, is $1.1 \cdot 10^8$ cycles.

Table 5

Regime	c_i	f, Hz	σ_v, kgf/mm^2	σ_m, kgf/mm^2	c_{N_i}	K_p	K_f	$K_pK_f\sigma_v$	$c_{N_i}(K_pK_f\sigma_v)^m$	N_i
Takeoff	0,02	515	2,7	8,0	0,045	1,1	1	3,0	$2\cdot10^6$	$6,2\cdot10^{12}$
		691	3,1	8,0	0,06	1,1	1	3,4	$2\cdot10^7$	$8,5\cdot10^{11}$
0.85 of rated	0,35	230	5,0	6,3	0,35	1,07	1,2	6,4	$2,4\cdot10^{12}$	$3,9\cdot10^7$
		1050	2,8	6,3	1,6	1,07	0,7	2,1	$2.2\cdot10^3$	$2,0\cdot10^{16}$
		3410	4,1	6,3	5,2	1,07	0,7	3,1	$3,6\cdot10^8$	$3.9\cdot10^{13}$
0.6 of rated	0,12	675	1,5	4,9	0,36	1,06	1	1,6	$6.6\cdot10^9$	$1.5\cdot10^{17}$
0.4 of rated	0,09	1810	2,0	3,5	0,69	1,04	1	2,1	$9,9\cdot10^4$	$2,0\cdot10^{14}$
		2360	3,0	3,5	0,93	1,04	1	3,1	$6.6\cdot10^7$	$3,9\cdot10^{12}$
		4420	1,8	3,5	1,74	1,04	1	1,9	$4,2\cdot10^4$	$9,7\cdot10^{14}$

From a comparison of the limiting longevities with consideration of asymmetry we see that accrued operating time at maximum stresses has a decisive influence on exhausting the service life. With operation only in this regime for the same reserve factor the equivalent number of cycles is $3.9\cdot10^7$.

A more reliable check of the resistance of parts to variable loads is accrued operating time for each resonance greater than $2\cdot10^7$ cycles. If we begin with a 10% frequency spread for each form of oscillation, to verify the working ability at all possible resonances we must introduce an accrued operating time in the stages of revolutions which do not differ by more than 10% from one another. If the accrued operating time is 50 hours in each stage, $2\cdot10^7$ cycles of operations will be assured for all forms with frequencies above 110 Hz.

Accrued operating time at critical revolutions checks the fatigue limit of housing parts, pipes, casings, supports, and also the operational reliability of units, the contact fatigue of slide-valve couples and other moving elements having small clearances.

If the operating range of the revolutions includes the critical velocity we must displace the stage of resonance revolutions until it coincides with the critical revolutions and accumulate operating time with them at maximum housing vibrations.

The number of cycles which are accrued for a given critical velocity are determined by the revolutions of the rotor, and are $N = 60\ n\tau$ cycles, where n are the rotor revolutions (rpm) and τ is the accrued operating time (hours).

An accrued operating time of 10^7 cycles, which can be considered as quite sufficient to estimate the fatigue limit of housing parts, particularly steel ones, with revolutions of 3000-7000 rpm is realized in approximately 50 hours.

Startups and engine accelerations are used to verify the heat resistance of turbine blades and combustion chambers, and the sensitivity of disks, shafts, supports, and blade joints to repeated static loading. The number of startups and accelerations in the equivalent program should correspond to their total number in the complete program.

With consideration of the mutual influence of stress-rupture strength, fatigue limit, repeated static loading, heat resistance, and wear, the equivalent program should be composed of several steps, each of which contains verification relative to all factors.

Figure 5 shows one of the 2-hour steps of the program, consisting of the above-enumerated constituent elements. Five hundred of these steps with a total duration of 1000 hours of programmed accrued operating time are equivalent, for most of the engine units and elements, to a 5000-hour program of long-term bench tests.

One step of the equivalent program includes the following:

26 minutes (approximately 210 hours in all) of accrued operating time in this regime relative to the complete program. Continuous accrued operating time in the takeoff regime is 13 minutes, which is

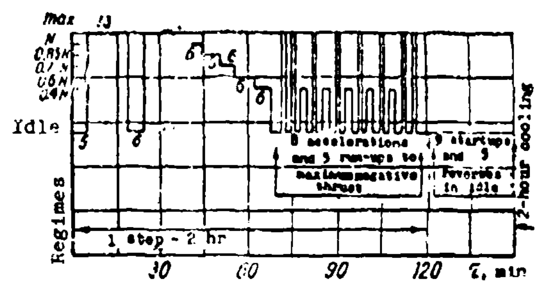

Fig. 5. Program of equivalent tests.

close to the value given in the usual programs. In addition, this is the time for almost complete heating of the disks;

1 (total of 500) cold run-up to the takeoff regime, which corresponds to the number of 10-hour steps in the total program:

1 (total of 500) deceleration and repeated run-up to the takeoff regime with maximum reverse temperature differential for the disks;

6 minutes (50 hours total) of accrued operating time at each of the resonances and at critical speed, which corresponds to an accrued operating time of $2 \cdot 10^7$ cycles beginning with frequencies of 110 Hz, and 10^7 cycles at critical revolutions, beginning at approximately 3000 rpm;

10 startups and 10 accelerations (5000 each, total), 5 run-ups to maximum negative thrust and 5 reverses at idle (2500 each, total), which corresponds to their total number for the total service life;

2-hour shutdown between steps, necessary for sufficiently complete cooling of the disks before a cold startup.

Equivalent tests conducted for a number of engines according to a program close to that given above for a service life of 5000 hours confirmed the identical nature of the detected defects and defects after usual long-term tests for total service life, and thus proved the possibility of using accelerated tests for the rapid detection of defects and for finding measures to overcome them, and also to estimate the capabilities of an engine when establishing the technical service life.